Power Consumption Analysis in the Machining of Ti-6Al-4V Titanium Alloy

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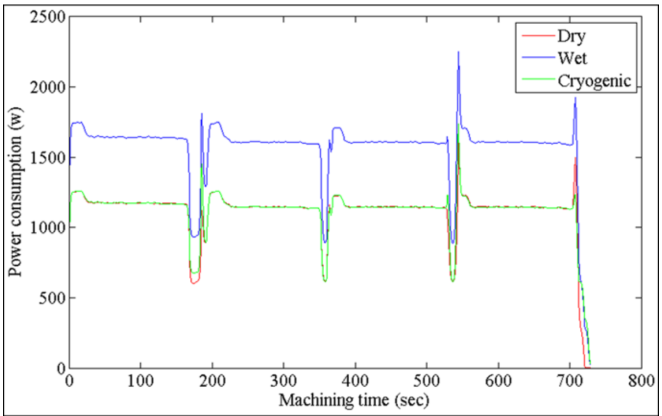
Abstract

Due to the excessive heat generation and poor thermal conductivity, machining titanium and it alloys has always been considered a challenge. One of the most common approaches to control the generated heat in machining titanium alloys is using a generous amount of cutting fluids. However, there are evidences indicating that flood cooling is not always beneficial for improving machinability of heat resistant alloys. Moreover, traditional cutting fluids are known to be environmentally hazardous substances [1]. Over the last few years, cryogenic cooling using liquefied gases has attracted a significant body of research as an environmentally friendly alternative to flood cooling. The majority studies on cryogenic machining stated that cryogenic cooling has significantly improved the machinability of titanium alloy through improved tool life and surface finish [2]. However, there is a lack of studies on the effects of the machining environment on the power consumption of the machine tool [2].

A total of 27 machining experiments were conducted under three machining environments namely, dry, flood and cryogenic at various combinations of cutting parameters. The machining experiments consisted of end milling of aerospace grade Ti-6Al-4V titanium alloy using coated solid carbide cutting tools whilst the total power consumption of the machine tool was monitored. A Gaussian filter was used to remove noise from measured data and the filtered data was used for statistical analysis. As shown in figure 1, irrespective of cutting parameters, power consumption in flood cooling is significantly higher than dry and cryogenic machining. Analysis indicated that power and energy consumption in flood cooling is 40% to 80% higher than dry and cryogenic machining. This is attributed to the power consumption of the coolant pump.



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Further statistical comparison of power consumption in dry and cryogenic machining indicated that cryogenic machining increases the power consumption by a maximum of 4%. The study indicated that whilst the power consumption in cryogenic machining was slightly lower (1%) than dry machining at lower feed rate (0.03mm/tooth), it was higher at higher feed rates of 0.055mm/tooth and 0.1mm/tooth. This can be explained by the fact that at lower feed rates, the cutting operation can benefit from a lubrication effect of liquid nitrogen whilst it evaporates faster at higher feed rates and fails to reach the cutting zone.

Furthermore, at higher cutting speeds, dry machining benefits from material softening as a result of heat generation at the cutting zone which results in lower cutting forces and thus power consumption. Since dry machining of titanium alloy is limited to low cutting speeds and feed rates, cryogenic machining has been shown to have significant potential for reducing power consumption at higher cutting speeds and feed rates, typically used in current industrial practice.

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2. Shokrani. A, Dhokia, V., Muñoz-Escalona, P., Newman S.T, 2013. State-of-the-art cryogenic machining and processes. Int. J. Computer Integrated Manufacturing, vol. 26(7), pp.616-648.